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PETROLEUM PLANTATIONS FOR FUEL AND MATERIALS

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INTRODUCTION

The problem with which we are faced in Japan, Israel, Brazil, the United States and Western Europe is the fact that we are so heavily dependent on the importation of fossilized fuels from other parts of the world. The reason is best shown in Figure 1 which depicts the use of energy in the United States in 1976. (My impression is that the use of energy in the other parts of the world mentioned is not a great deal different from this, except that the overall dependence is greater.) The principal messages which Figure 1 will provide are, first, that practically all of the energy (natural gas, coal, petroleum) that we use is fossilized photosynthetic energy; there is a small amount of nuclear, geothermal and hydro which varies a bit in different parts of the world. It is still a fact that by far most of the energy used is fossilized photosynthetic hydrocarbon of one sort or another, laid down many millions of years ago.

The second message conveyed by Figure 1 is that about one-half of the energy which is put into the system in the form of primary energy is lost (i.e., rejected energy) and only the other half is useful energy. The reason for that fact is visible in the loss bars from electricity generation and transportation in which the energy is first converted into mechanical work. Because the energy must be converted into mechanical work the useful output that one can obtain is limited by the Carnot limitation which says that the amount of useful work which can be obtained from an energy flow depends on the temperature difference between which the energy is flowing.

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The energy is flowing from a higher temperature to a lower temperature, and in so flowing is doing work, much as water going from a high altitude to a low altitude. The Carnot principle states that the maximum amount of useful work which can be obtained from the energy flow is determined by the temperature difference between which that heat flow occurs. For the most part, in the internal combustion engine which is used in transportation (such as an automobile engine or even a gas turbine such as used in an airplane) the efficiency is very low (less than 20%). In a public utility when the energy is used to drive a turbine to run a generator, the energy can be used somewhat more efficiently because the high temperature at which that turbine runs can be as high as the material of construction will stand; this means that the electrical generation occurs at about 30% efficiency and the losses are considerably smaller than they are for the internal combustion engine.

When the time comes for us to find alternative energy sources I will turn to the sun, but I will not use the sun solely as a heat source, because if I do I will again by limited by the Carnot limitation. If I obtain the sun's energy and convert it first to heat and then back down into work, the efficiency is small. Therefore, I do not recommend that type of activity.

There is one other point to which I would like to call your attention: That is, about 10% of the total fossilized carbon is going into what is called a non-energy use. That non-energy use will be recognized as the petrochemical industry. We make most of our materials from hydrocarbons which are often first cracked down to ethylene as a rpimary raw material and the ethylene and propylene may be built up into most other materials, such as synthetic fibers, plastics, etc. Is that that ten percent of energy usage that I think we will be able to fulfill first by alternative energy sources to petroleum.

The historical use of energy is shown in Figure 2. The growth of petroleum use has been immense over the period 1958-1978. Natural gas reached its peak in 1968 and has remained more or less as a fixed fraction of the total. Nuclear remains a relatively small part of the total, as do hydro and geothermal.

You can see the discovery of crude oil as a function of the number of feet of well drilled in Figures 3a and 3b. In the years from 1920-1950 the discovery rate was very nearly constant; we found the same number of barrels of oil for the same million feet of well drilled. By 1950, however the oil supply was diminishing and the slope fell to about one-fifth, meaning it was necessary to drill five times as many wells, or five times as deep wells, to get the same amount of oil. If you put the concept the other way, you get one-fifth as much oil per well drilled now as we did in the early part of the twentieth century. This information is fairly objective evidence that the availability of oil in the continental United States is now decreasing. Figure 3b shows the crude oil discoveries per foot of drilling in another form, which again indicates the greater effort required now to obtain the necessary petroleum. The same phenomenon actually applies to the entire globe in spite of the discoveries in Alaska, Mexico, China, etc. The rate of discovery on a global scale is declining. There have been some studies by the U.S. Geological Survey about drilling and oil discoveries in non-Communist countries other than the United States and Canada. They also have found a negative-exponential decline in the oil found per well vs. the number of wells drilled, similar to the data for the United States. These studies estimate that the peak in oil production rate for this block of countries will probably occur in the 1990 decade.

We also have objective evidence that the amount of oil that can be recovered is being gradually exhausted, which is what you would expect since the oil is simply the residues of ancient photosynthetic activity of green plants. Mr. King Hubbert, a geologist from the U.S. Geological Survey, has estimated how much oil there might be to recover and how long it might take. He has also done a similar thing for coal. These two patterns (for oil and coal) are shown in Figure 4 which gives both the historical facts and the projection for the future. Notice that in 1800 most of our energy was from a renewable source, wood, with coal not coming in until about 1850, and then petroleum in the early part of the twentieth century surpassed coal. By the end of the twentieth century the oil will be exhausted. The area under the dark bell curve of Figure 4 is the total amount of oil which might be found on the earth, estimated by King Hubbert in various ways which are fairly reliable in a general manner. A similar estimate has been made of the amount of coal which might be recoverable on the earth's surface, and you can see that the area under the coal curve is enormously greater than the area under the oil curve. This has led a number of people to suggest that we could move our resource (energy and materials) to a coal base instead of an oil base, which is, in actual fact, being done in many industries and countries.

THE CARBON DIOXIDE PROBLEM

There are some constraints on the increased use of coal on the scale proposed to which I want to call your attention. We cannot expect to use coal indefinitely on an expanding scale because of the increase on the amount of carbon dioxide as a result of the burning of coal. (CO_2, of course, results from the burning of any fossil fuel, but with greater amounts from coal.) In addition to the production of carbon dioxide, burning of coal products aromatic hydrocarbons (carcinogens) and ash, but these are environmental constraints and hazards which can be cured with the expenditure of money and effort. However, it is not possible to reduce the amount of carbon dioxide as a result of increased coal consumption.

In order to burn the coal, it is necessary to produce CO_2 and there is no way to capture that carbon dioxide with a net reduction of atmospheric levels before it gets into the atmosphere. There is really no way to reduce CO_2 generation with coal burning because there is more CO_2 produced per energy unit from coal than from oil. (Oil burns both carbon and hydrogen and coal burns only carbon, thus resulting in more CO_2 per unit of heat).

The fact that CO_2 results on such a large scale has been observed experimentally (Figure 5). The carbon dioxide of the earth's atmosphere has been measured at five different places during the period 1958-1978. The concentration of CO_2 during that twenty year period has risen from about 300 ppm to 330 ppm. The data, which are the result of direct CO_2 measurements in five different locations, can be extrapolated backwards using data obtained from isotopic ratios (the ratio of carbon-13 to carbon-12) in ancient tree rings. From that data one can estimate what the carbon dioxide content of the atmosphere was in 1860, for example. At that time it is estimated to have been as low as 290 ppm. The increase of CO_2 has been about 15% in one hundred years, with 5% increase in the last fifteen years (Figure 5). The extrapolation forward is derived from various individuals who have different estimates of how much CO_2 will remain in the atmosphere and depends on how much fossil carbon is burned. All feel that the concentration of CO_2 will rise about the present 330 ppm to over 400 ppm and some estimates are as high as 500 ppm.

Why should we be concerned about the increase in carbon dioxide in the atmosphere? The answer lies in the fact that carbon dioxide is transparent to visible light but opaque to infrared light. The sunshine coming in as visible light passes through the CO_2 blanket, and when the sun strikes the surface of the earth it turns into heat and is reradiated as infrared. However, when it comes out into the atmosphere as infrared it cannot escape because the carbon dioxide is opaque to infrared. Therefore, the infrared heat is absorbed and reradiated by the CO_2, back down to the earth, thus increasing the temperature (Figure 6).

The earth may be expected to become warmer because of the increasing thickness of the CO_2 blanket which will be formed as the carbon dioxide level in the atmosphere increases. The estimates of what that temperature rise might be have been made by a number of meterologists. There is no agreement as to the details of how high that temperature will be, or how the climate distribution across the earth will change with rising carbon dioxide. I will give you one example by one meterologist of an estimate. The dotted line in Figure 7 is the estimated change in carbon dioxide concentration, rising from 300 ppm to over 600 ppm in one hundred years as the CO_2 level increases. If we continue to burn coal beyond 1980, the carbon dioxide delivered into the atmosphere will rise and increase to a concentration of 600 to 800 ppm.

What might be the average temperature consequence of the rise in CO_2 concentration? The temperature rise may be as high as two to give degrees centrigrade (global average), a very large change which will have very profound effects on the climate distribution on the earth's surface. Parts of the earth which are today useful agricultural regions will become deserts; other parts which are frozen may become useful; and the entire pattern of human activity on the earth's surface will be profoundly changed in a relatively short time, in less than one hundred years.

It is doubtful that the human race will be able to adjust to that change in the short time available if the change goes forward as projected. Thus, we do not actually have the freedom to use the coal indefinitely because it will cause a tremendous increase in carbon dioxide concentration.

The environmental constraint with increased coal use is such a serious one in terms of carcinogens, particulates and carbon dioxide that we should not be permitted to indiscriminately transfer our whole need for energy and materials into coal.

GREEN PLANTS AS SOURCES OF FUEL AND MATERIALS

It is imperative to find another and renewable source and the most obvious source is the sun itself. The possibility of harvesting the sun on a current basis instead of using our capital, which is represented by oil, coal and natural gas as a result of ancient photosynthesis, means we could use our current income from the sun, renewable annually.

What is the best solar converting machine we have? The best one available today is the green plant. Of the green plants, the one we know best and which has been cultivated for its efficiency in terms of energy capture and its useful product is sugar cane. The sugar cane is harvested and the resulting sugar juice can be converted into a useful fuel and materials form by fermentation, the reactions for which are shown below:

$$\begin{array}{lcl} C_6H_{12}O_6 & \longrightarrow & 2\ C_2H_5OH \ + \ 2\ CO_2 \\ 180\text{ gm} & & \qquad 92\text{ gm} \\ (673\text{ kcal}) & & \qquad (655\text{ kcal}) \\ 12.88\text{ lbs} & \longrightarrow & 1\text{ gal } (84{,}356\text{ Btu}) \end{array}$$

Cost/gal - raw material + 20¢ process cost

The sugar is still only half-reduced carbon, with one oxygen atom for every carbon atom, and the fermentation process is very efficient. Notice that the amount of energy contained in the sugar is almost all retained in the resulting liquid alcohol. The liquid alcohol is a further reduced carbon compound (one oxygen atom for two carbon atoms) and thus more useful.

It is worth mentioning at this point that the large sugar plantation, especially in Brazil, is a completely self-sufficient net energy producing farm, having the sun as its sole energy input. The bagasse (lignocellulose), remaining after the sugar-containing juice is expressed, is burned in boilers to produce enough steam not only to run the entire sugar mill and fermentation-distillation facility but to produce excess electricity which is more than equivalent to the ammonia fertilizer that might be required on the sugar cane.

The Brazilians have undertaken to convert their sugar cane to fermentation alcohol on a huge scale. In 1978 the Brazilian production of fermentation alchol from sugar cane was 2.7 billion liters, partly from molasses and partly directly from sugar cane juice, and in 1979 the plan is to produce 4 billion liters of fermentation alcohol. The facilities are already in place and the new sugar cane acreage to make this production possible is under cultivation. The Brazilians can use the alcohol from sugar cane as a fuel. Gasoline can be diluted by 20% alcohol which requires no substantial modification of automobile engines, or it is possible to use 95% alcohol-water, in which case automobile engines must be modified by the addition of a small heat exchanger between the carburetor and the intake manifold to vaporize the droplets of alcohol.

You can imagine that the chemical industry is undertaking to build in Brazil many cracking plants which prdouce ethylene from the alcohol. This is a result of the increased supply of fermentation alcohol from sugar cane. Instead of cracking naphtha to make ethylene and petrochemicals the manufacturers will crack fermentation alcohol to make ethylene (and from there to polyethylene, polypropylene, ethylene glycol, ethylene oxide, etc.). This fermentation alchol which is being made from the sun through the sugar cane via fermentation will supply not only most of the Brazilian fuel needs but some of their material (chemical) needs as well.

In the United States we cannot grow sugar cane on the scale required for the production of fermentation alcohol on an economic basis, However, corn, a close botanical relative of cane, does produce directly fermentable carbohydrate. The State of Nebraska is trying to encourage the development of a fermentation capacity so that it may be able to divert a fraction of the corn grown for stock feeding into the fermenters, thus producing alcohol for mixing with gasoline (gasohol), with the resultant distillers' dried yeast replacing corn in the cattle feed. The production of gasohol is also a net energy producing operation and may also be a net money (economic) one as well.

Hydrocarbon Producing Plants

Three steps are required to go from carbon dioxide to a hydrocarbon. First, the plant must take the carbon dioxide from the air and reduce it to sugar (half-reduced carbon) then the oxygen in the molecule has to be reduced to one molecule of oxygen for every two carbon atoms via fermentation (one-half oxygen per carbon atom). It is then necessary to remove that last bit of oxygen to produce a hydrocarbon.

There are some species of plants that take the carbon dioxide all the way down to hydrocarbon containing no oxygen at all. The one capable of doing this which is most familiar to you is the Hevea rubber tree which grows commercially on plantations in Malaysia, shown in Figure 8. In

Malaysia the trees are planted about three meters apart, and one person can cut the tap for 200 trees in one day. (This hand operation is a prin-ciapl source of skilled jobs for Malays.). The latex which emerges from the rubber tree on tapping is an emulsion of hydrocarbon in water, and the hydrocarbon has a high molecular weight (about two million) so that when the water is removed a solid hydrocarbon material remains, an elastomer known as rubber.

The Hevea rubber tree belongs to a member of the Euphorbiaeceae family and is related to another genus, Euphorbia, of which there are about 2000 species. Every single one of the Euphorbias we have examined produces a latex, but the Euphorbia latex has a molecular weight of the order of 20,000 instead of two million. Therefore, the Euphorbia latex is a much lighter hydrocarbon so the resulting material, after the water is removed from the emulsion, is a liquid oil and not a solid elastomer.

In the spring of 1977, after thinking about the problem of renewable resources for about three years, we were able to undertake plantings of several species of Euphorbia in Southern California at the South Coast Field Station of the University of California. Figure 9 shows the "petroleum plantation" at the end of 1978 and at the present time there are about five species of Euphorbia under cultivation. There is Euphorbia lathyris, an annual, two different plantings of Euphorbia tirucalli, a perennial, with Euphorbia myrisinites, Euphorbia trigona, Euphorbia bubelina and Euphorbia Mauritania. The Euphorbia tirucalli after one year's grown is shown in Figure 10 which is a plant started from cuttings about 5 cm long and 5 mm in diameter. The plant grew about a thousand-fold in one year. (Since this photograph was taken, the E. tirucalli were subjected to a period of frost and have died back except in the cases where the stems were at least one-inch in diameter. We are now waiting to see whether the E. tirucalli recover and continue their growth this second year; see Figure 11.)

The E. lathyris is shown close-up in Figure 12; it was grown from seed and planted on about two-foot centers. The yield data for the E. lathyris is shown in Figure 13 for a seven-month period. A more recent photograph of the Euphorbia lathyris is shown in Figure 14. This is of interest because the plants are not the same size. The one on the left was grown from seed from Southern California plants and the E. lathyris on the right was grown from seed from Nothern California plants. It will be interesting to learn if the composition and yield of oil from these two E. lathyris plants from two different seed sources will be identical, or whether there will be slight differences.

The material obtained from E. lathyris is a mixture of terpenes. All of them are isoprenoids and most of the materials are cyclic terpenes.(C_{30} and C_{20}). Figures 15 and 16 show some of the materials isolated from E. tirucalli and E. lathyris. The material found in the latex of E. tirucalli is phorbol, a C_{20} compound containing a small amount of oxygen. Ingenol (Figure 16) is present in small amounts in E. tirucalli but appears mostly in the latex from the E. lathyris. Both phorbol and ingenol are interesting materials as they have biological activity. This is another additional result from cultivation of Euphorbias. These two compounds, because of their biological activity, will increase usefulness of hydrocarbon plantations even further.

Most of the Euphorbias contain steroids of various types, and a summary of the steroids found in several different species is shown in Table I.

When we discussed this type of renewable resource activity a couple of years ago, a Japanese firm became interested and planted Euphorbia tirucalli on Okinawa with great success; the Okinawa plantation in March 1978 is shown in Figure 17. They treated the soil with polystyrene to make it porous and placed a polyetheylene shield over the ground to keep it warm during the initial growth stages. The same field of Euphorbia tirucalli in December 1978 is shown in Figure 18. You can see the spectacular results of that type of soil treatment under those particular climatic conditions. The grown curve for the E. tirucalli from the Okinawa plantation is shown in Figure 19 through December 1978. The Japanese company has calculated that with the present rate of growth they can extract five kilograms of oil per plant per growing year. With plants on four-foot centers that would mean a production of between 15 add 30 barrels of oil per acre per year. The yield of E. tirucalli in Okinawa is at least twice (more like three times) the yield of E. lathyris in California. In our calculations we have considered that the E. lathyris produces between 8% and 12% of its weight as oil which gives a yield of between 10 and 20 barrels of oil per acre per year.

There are presently experimental plantings of several Euphorbia species in Texas, Arizona and Florida as well as increasing interest in guayule for rubber production with plantings in Texas, Arizona, California as well as northern Mexico.

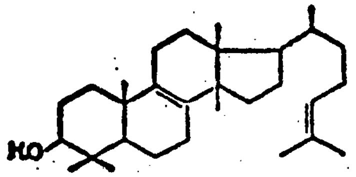
Euphorbias, of course, grow wild throughout the world in semiarid regions, and their cultivation can be accomplished without using land which is more productive for food and fiber. One of the earliest references (1940) to the use of plants of this type involved some work done by the French in

Table I

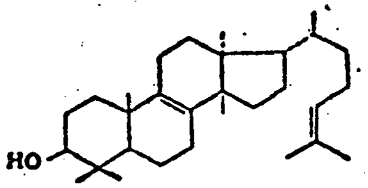
STEROIDS FROM PLANT LATEX

Species	Relative amount of sterols												Taxonomy Group
	a	b	c	d	e1	e2	f	g	h	i	j1	j2	
1 *Euphorbia aphylla*		.37		.10	0.82		1.0	.46					C_1
2 *Euphorbia arbuscula*	1.0	.19											B
3 *Euphorbia balsamifera*							1.0				.80		C_2
4 *Euphorbia characias*				.13	1.0		.68	.27					C_1
5 *Euphorbia coerulescens*	1.0	0.10	.20										A
6 *Euphorbia cylindrifolia*	1.0	.25				0.50							?
7 *Euphorbia globosa*								.30			1.0	1.0	?
8 *Euphorbia ingens*	1.0	.30											B
9 *Euphorbia lathyris*	.12			.80	.50		.30	1.0					C_1
10 *Euphorbia marlothii*							.41			.32		1.0	C_2
11 *Euphorbia misera*	.69	.32		.66			1.0						C_4
12 *Euphorbia obtusifolia*	.05				1.0	1.0	.80	.50					(C_1)
13 *Euphorbia stenoclada*	1.0	.16							.29	.17			(B)
14 *Euphorbia tirucalli*	1.0	0.10											B
15 *Euphorbia trigona*	1.0						.61						?
16 *Elaeophorbia drupifera*	1.0	.16	.20										A
17 *Achras sapote*									1.0^{+}	0.20^{+}			E
18 *Asclepias sp.*									1.0^{+}	0.20^{+}			E
19 *Synadenium grantii*	0.25	0.20	0.10		0.40	++							?

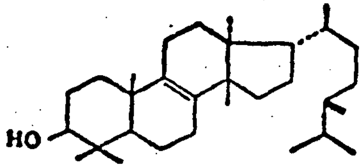
+



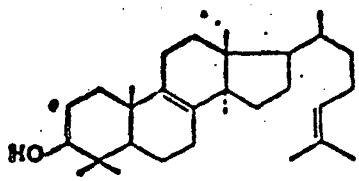
A Euphol



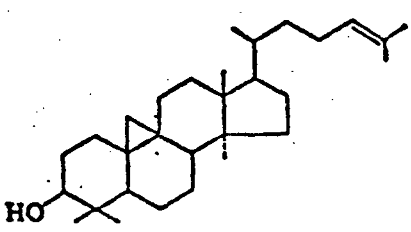
B Tirucallol



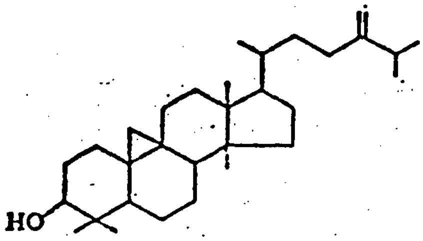
C Euphorbol



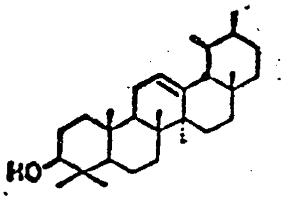
D Lanostérol



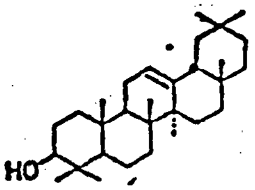
F Cycloartenol



G 24-Methylene cycloartanol



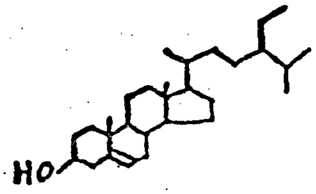
H α - AMYRINE



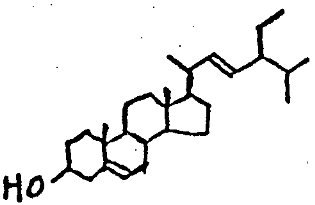
I β - AMYRINE

E Lanosterol isomer

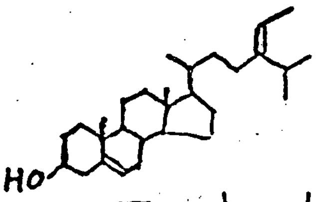
J Other Pentacyclics



β- Sitosterol



Stigmasterol



Fucosterol

Morrocco with Euphorbia resinifera. They were able to obtain a yield of three metric tons of oil per hectare from these plants; we were unable to find out how long these plants were grown and this number is only a single point for one harvest. Other species of Euphorbias grow in areas such as Morocco and a wild stand of these plants is shown in Figure 20. Additionally, species of Euphorbias grow wild in Ethiopia and the E. abyssinica in the area near Asmara is shown in Figure 21. Also, the Italians attempted to grow Euphorbias in Ethiopia in 1935-1936 to use their gasoline-like latex for fuel; however, it is not known whether or not this experiment was successful. It is interesting to note in the one reference to this work which we have been able to find that the statement is made (and this article was written in 1938) that ".....the experiment will be watched with interest since geologists inform us that the world's petroleum supply is limited and diminishing rapidly, and who knows but that the answer rests with the Euphorbiae."

I am completely confident that plants which grow in the semiarid regions of the world could be used to fulfill some of our chemical and energy needs for hydrocarbons.

ECONOMIC CONSIDERATIONS FOR HYDROCARBON-PRODUCING PLANTS

I would now like to give some estimates of the cost of developing the hydrocarbon-producing plant plantations and process machinery which have been made by two quite independent commercial sources in the United States. One was made at our request by the Stanford Research Institute in Palo Alto, California as to what the cost of the oil produced from hydrocarbon-producing plants would be. The only data we had available was the ten barrels of oil per acre per year. They arrived at a certain figure about two or three months ago.

Recently, I had a quite unexpected telephone call from the Chevron Research Laboratory of the Standard Oil Company of California. They had also made an economic analysis of the costs of hydrocarbon from Euphorbia lathyris plants. Presumably they did it to see if there was any reason for them to be interested in projects of this type. The interesting fact is that with the same data (ten barrels of oil per acre per year and the undeveloped extraction process--a crude laboratory process with no engineering data) they arrived at almost the exact figure we had received from the Stanford Research Institute (Table II). These two sources did not know of each other's calculations.

The numbers which resulted from these economic analyses were $20 per barrel of oil for operating costs and $40 per barrel of oil capital costs (construction of extraction plants, process development, etc.), making a total of $60 per barrel of which two-thirds was capital investment for a 1000 barrel per day pilot plant. Since two-thirds of the cost is capital cost and since that is determined by the size of the plant, we can expect a plant of commercial size (100,000 barrels per day) to have a capital requirement of $5 per barrel. If the yield of oil instead of being ten barrels of oil per acre per year is twenty or even thirty, the operating cost would be reduced proportionately to ~$10 per barrel, thus making a total cost of ~$15 per barrel. You know that today (March 1978) we are paying more than $15 per barrel of oil, and with recent worlwide events in the Middle East, you can be sure that the cost of oil will increase.

If with wild plants in Okinawa we can get 30 barrels of oil per acre per year and in California 20 barrels of oil per acre per year, the price of the refined oil from hydrocarbon-producing plants will be anywhere from $10 to $30 per barrel, including capital costs. These dollars, instead of adding to our foreign trade deficit as happens with imported oil, would be spent in the United States. It seems to me that we are very close to having a renewable resource for chemicals and for energy.

It will be necessary to develop a substantial acreage for the cultivation of hydrocarbon-producing plants, i.e., hundreds of millions of acres will be required, which will take time to develop even if we start immediately. The time required here is such that we are very close to balancing the fulfillment with the demand. I hope that enough activity and interest is generated in this type of development in Japan, the United States, Africa, Israel and other parts of the world so that the petroleum plantations can develop fast enough to become visible as resources before it is too late.

I have no doubt that we will be able to improve the yield of hydrocarbon from the plants by selection and genetic manipulation, just as the yields from the Hevea reubber tree were improved by the Malaysians. If we start with ten barrels of oil per acre per year, we should be able through the use of plant tissue culture methods, improved agonomic practices, to get not less than fifty barrels of oil per acre per year. I

TABLE II

COMPARISON OF INDEPENDENT EVALUATIONS OF OIL FROM EUPHORBIA PROCESS

(ALL FIGURES ARE $ PER BARREL)

(100% EQUITY FINANCING ASSUMED)

	CHEVRON (1000 bbl/day facility)	SRI (1600 bbl/day facility)
Feedstock		
Cost from farm	11*	30**
Credit for bagasse	-	19
Net feedstock cost	11	11
Other operating costs	10	14
Capital cost (amortization, 15% return, etc.)	46	41
Total production cost	67	66

* This is an unrealistically low figure based on a 20 bbl/acre yield at an annual agricultural cost of $200/acre. There is no evidence to indicate that the corresponding 36 dry tons of biomass can be produced for $200. On the other hand, Chevron took no credit for the byproduct bagasse, thus coming up with a net feedstock cost of $11/barrel.

** In the SRI study the feedstock cost was based on our own data of 12 dry tons/acre/year at an estimated $200. The bagasse is sold at $1 per MM Btu, or $19/barrel of oil product, leaving, again, coincidentally, a net feedstock cost of $11/barrel.

know this improvement in yield will occur, as will modification of the oil composition from the plants to more desirable compounds.

CONCLUSION

It appears that the possibility for the development of an economically useful solar energy and materials system is an outgrowth and, in a sense, a return to an older system--the use of the best existing solar energy-capturing device we know, the green plant, by selecting and modifying it to produce the materials we would like to have, namely, hydrocarbons of suitable molecular weight and structure. The choice of the particular plants with which to begin such a large-scale development has yet to be made, although information is currently at hand which will make such a decision feasible in the near future. The choice of particular plant(s) will depend on growth rates and habits, hydrocarbon productivity and harvest adaptability, as well as process development. Our experiments, and those of others, have indicated the economic feasibility of the production of oil from hydrocarbon-producing plants, and with the continued increase in cost of petroleum from fossilized photosynthetic residues and the continued decrease of its availability, the development of this alternate energy source becomes absolutely necessary.

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FIGURE CAPTIONS

1 U.S. energy flow, 1976 (XBC 776 5733)

2 Energy consumption by primary energy type (XBL 781 12004)

3 Crude oil discoveries per foot of drilling vs. depth of drilling (King Hubbert)
a XBL 776 4467
b XBL 7812 13093

4 Oil and coal use cycles (King Hubbert)(XBB 778 7577)

5 Carbon dioxide in the earth's atmosphere 1860-2040 (Kellogg) (XBL 783 3858)

6 Greenhouse effect (XBB 779 8871)

7 Strategy for CO_2 impact of fossil fuel (Williams) (XBL 789 4223)

8 Rubber tap (CBB 757 5366)

9 Petroleum plantation, South Coast Field Station, Santa Ana, California November 1978 (CBB 780 15629)

10 Euphorbia tirucalli, Santa Ana, November 1978 (CBB 780 15631)

11 Euphorbia tirucalli, Santa Ana, February 1979 after 28°F freeze (CBB 792 2780)

12 Euphorbia lathyris, Santa Ana, November 1978 (CBB 780 15635)

13 Growth curve, Euphorbia lathyris (seven months period)(XBL 7810 4299)

14 Euphorbia lathyris, Santa Ana, February 1979, showing seed difference. Northern California seed, front; Southern California see, rear (CBB 792 2782)

15 Phorbol esters in Euphorbia tirucalli extract (XBL 793 9031)

16 Ingenol esters in Euphorbia lathyris extract (XBL 793 9032)

17 Euphorbia tirucalli, Okinawa, Japan, March 1978 (CBB 785 6449)

18 Euphorbia tirucalli, Okinawa, Japan, December 1978 (CBB 793 3190)

19 Growth curve Euphorbia tirucalli, Okinawa, Japan, December (XBL 793 4687)

20 Euphorbias growing wild in Morocco (CBB 791 210)

21 Euphorbia abyssinica, Asmara, Ethiopia (CBB 792 2288)

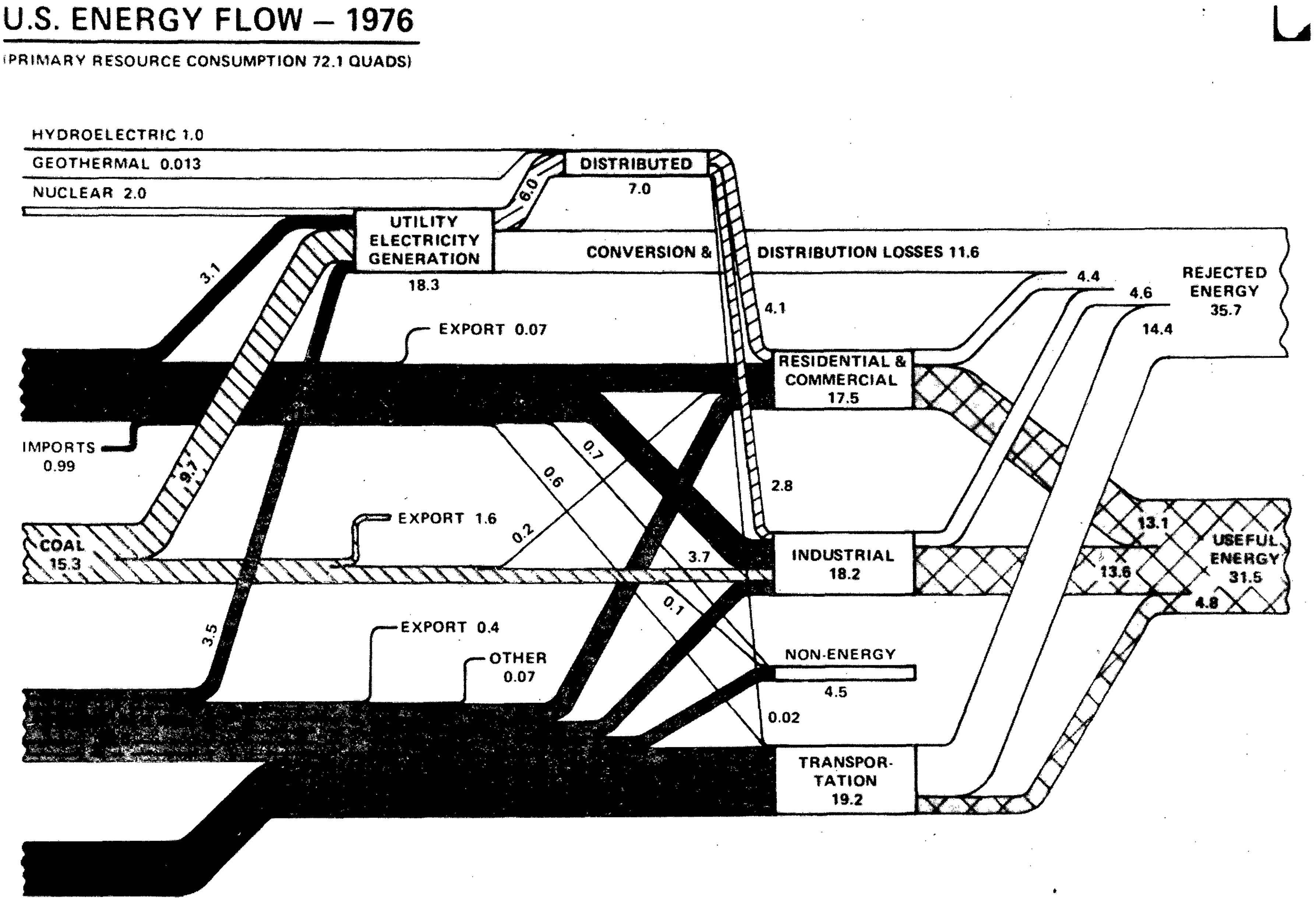
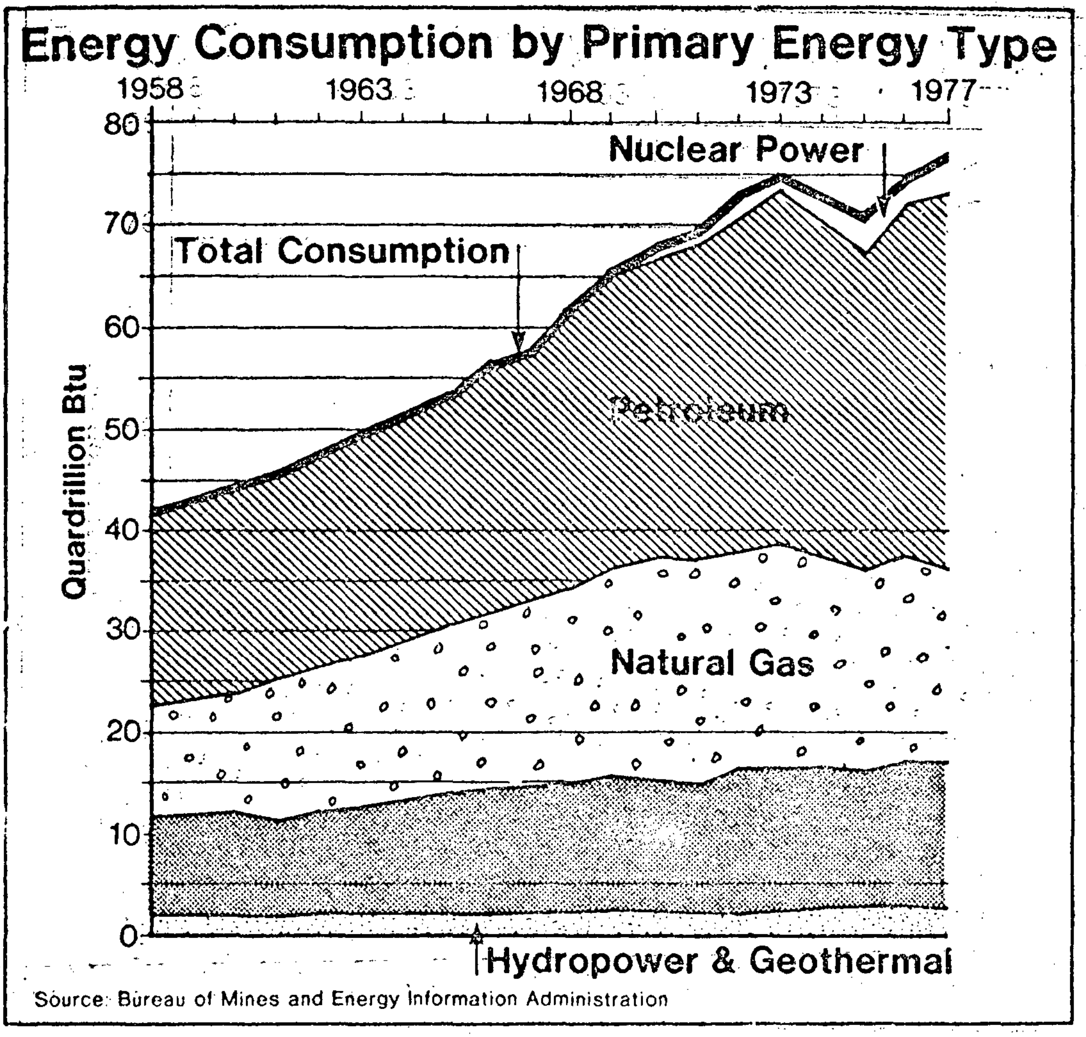


Fig. 1 U. S. Energy Flow, 1976

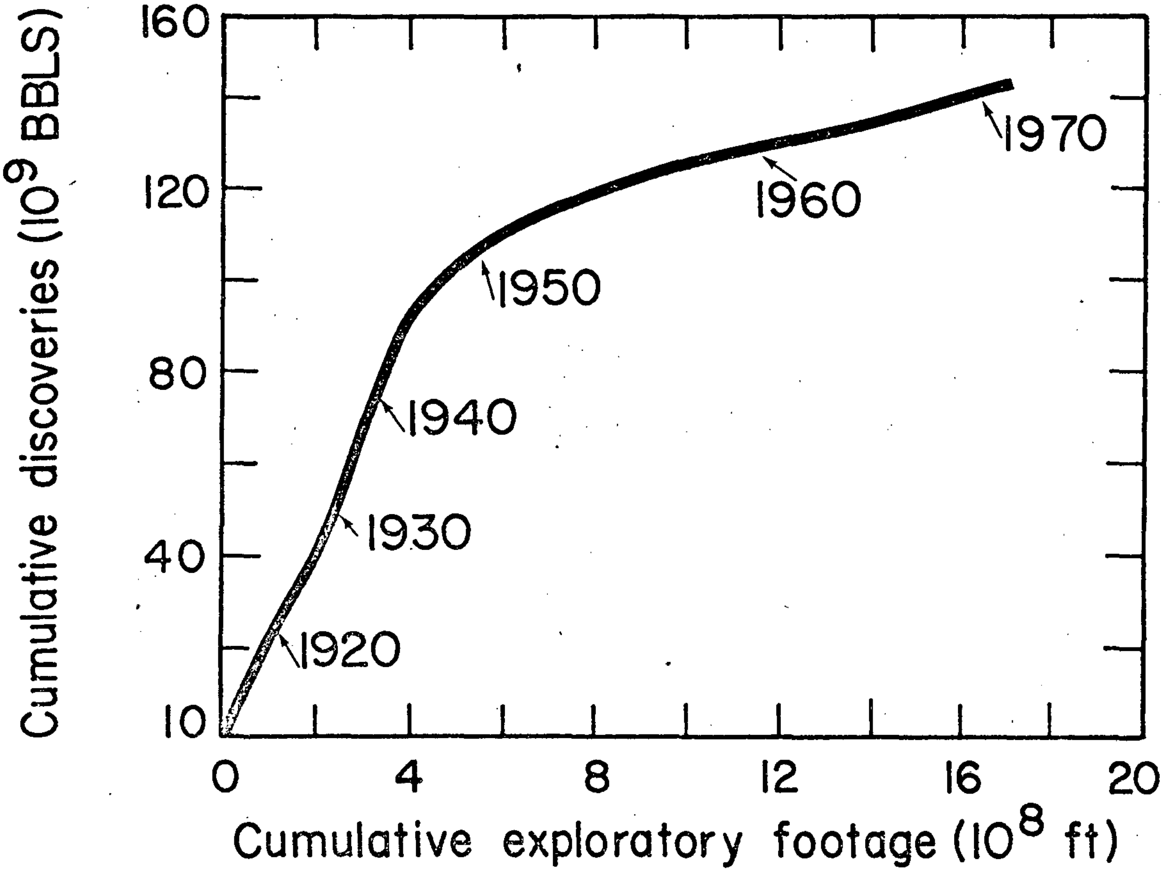
XBC 776-5733



XBL 7810-12009

Calvin

Figure 2

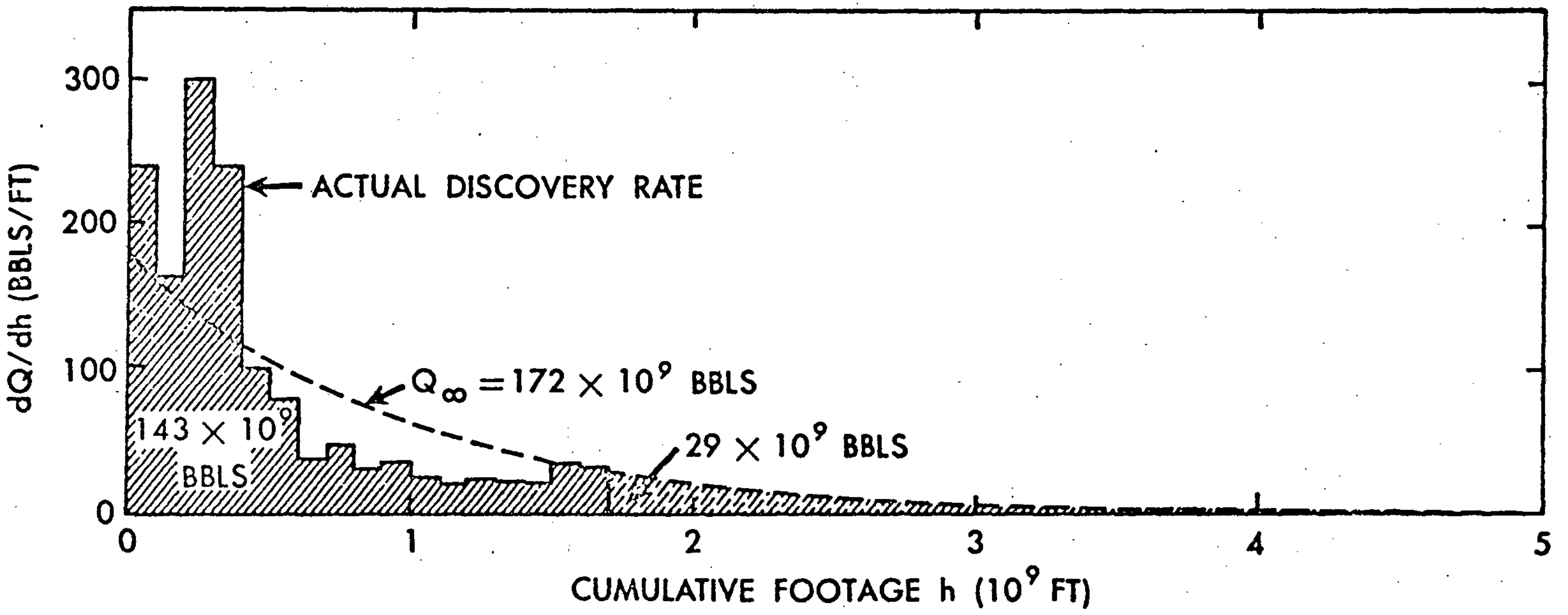


Cumulative U.S. crude-oil discoveries as a function of cumulative depth of exploratory drilling. (King Hubbert, 1974)

XBL 776-4467

Calvin

Figure 3a

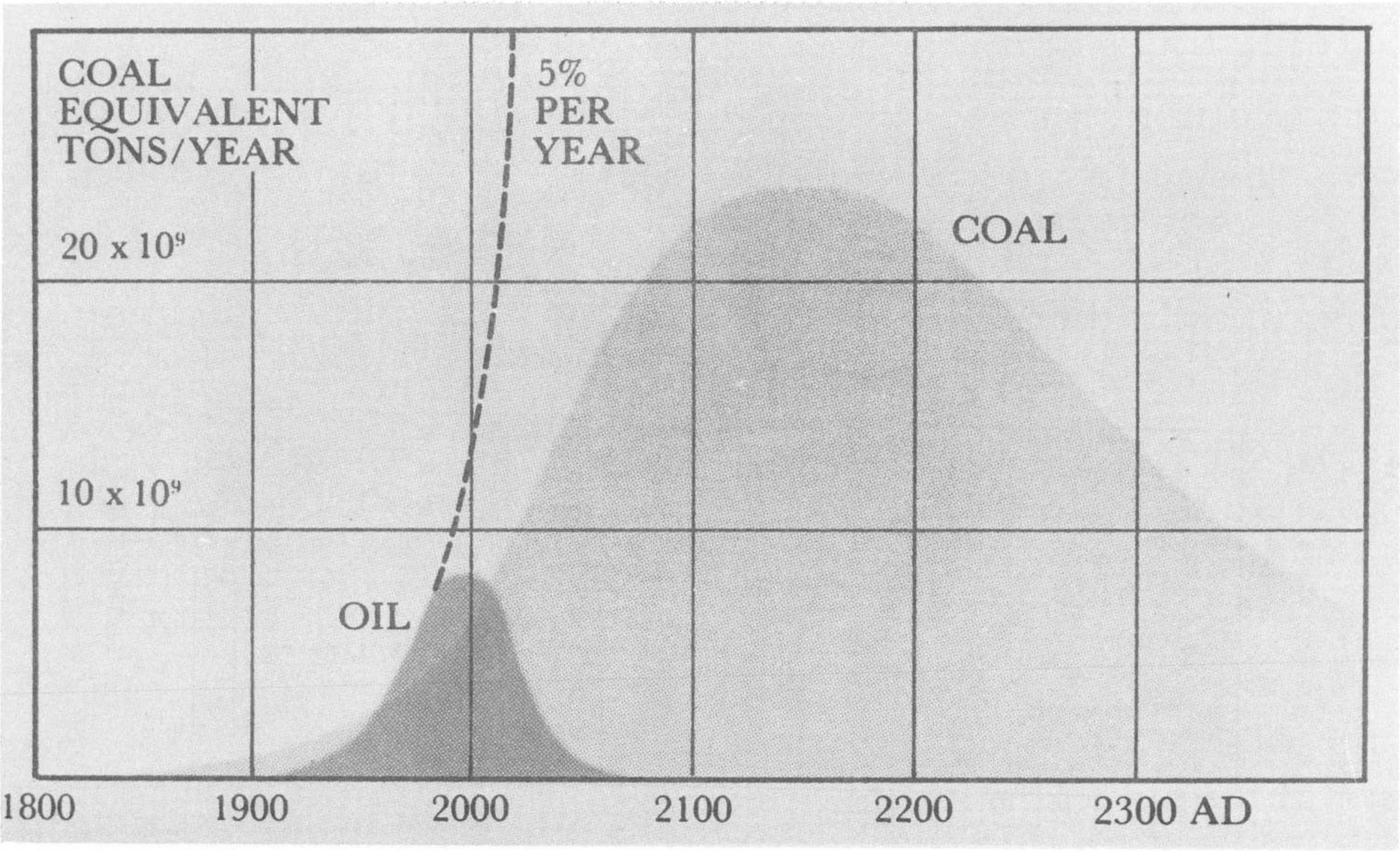


Crude-oil discoveries per foot of exploratory drilling versus cumulative depth of exploratory drilling in U.S. Lower-48 states (Hubbert, 1974) Fig. 50).

XBL 7812-13093

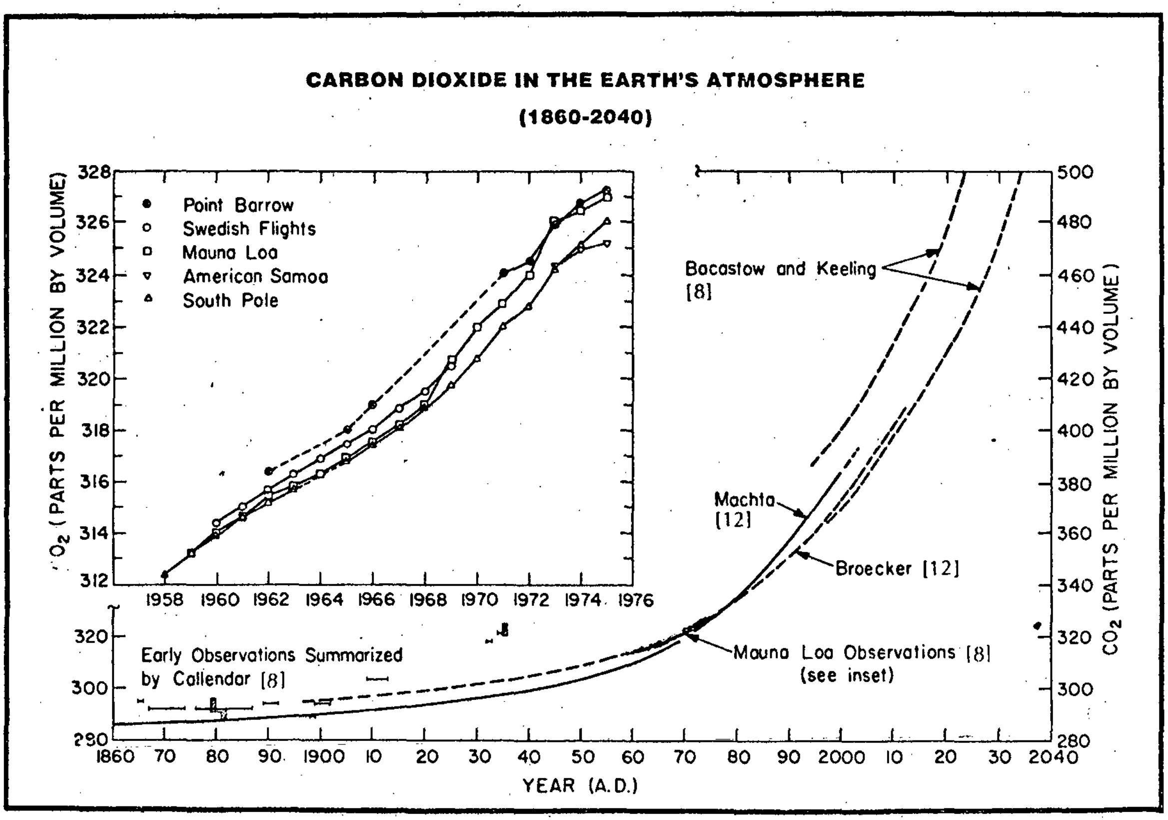
Calvin

Figure 3b



XBB 778-7577

Fig. 4



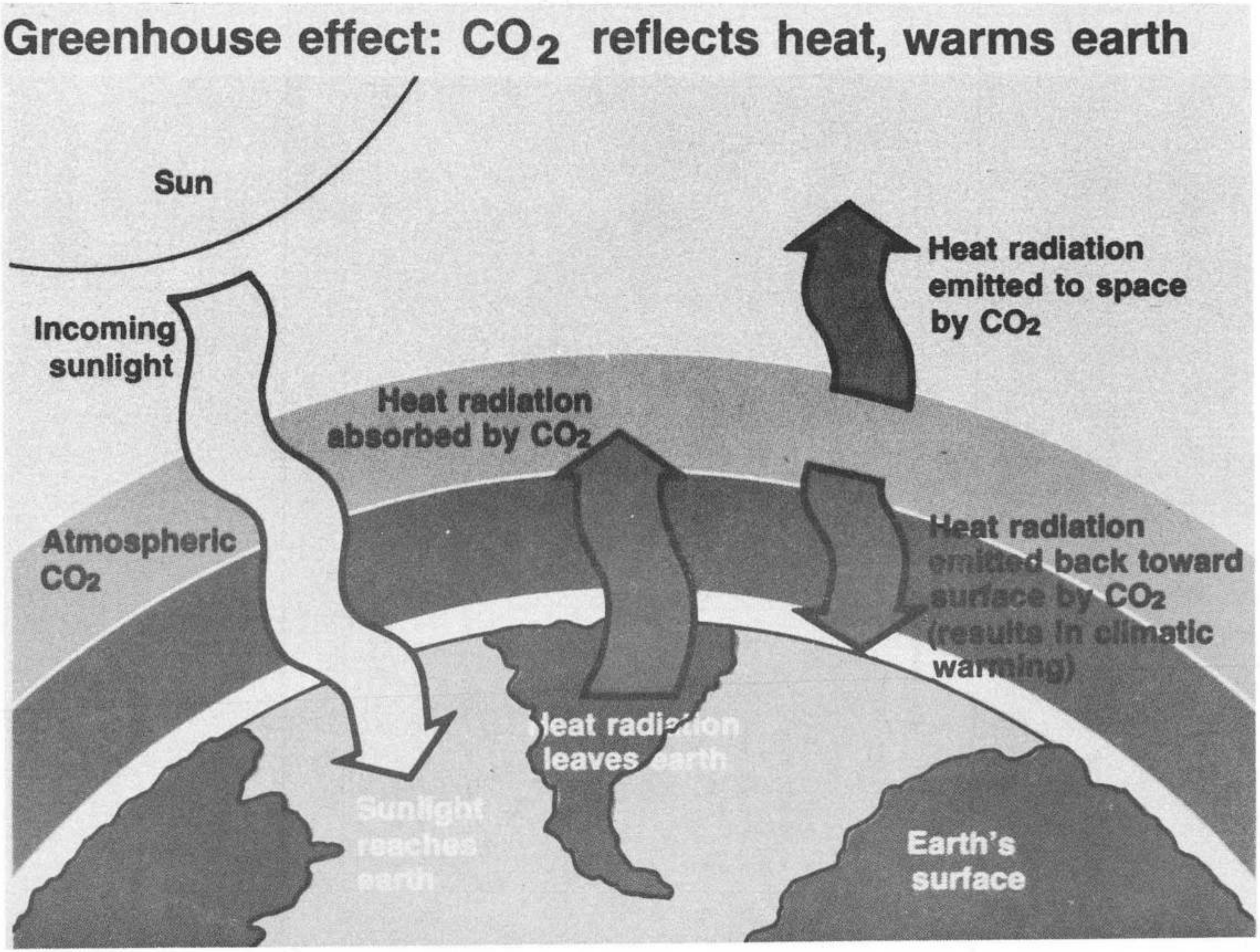
CARBON DIOXIDE IN THE EARTH'S ATMOSPHERE (1860-2040)

W.W. Kellogg

XBL 783 - 3858

Calvin

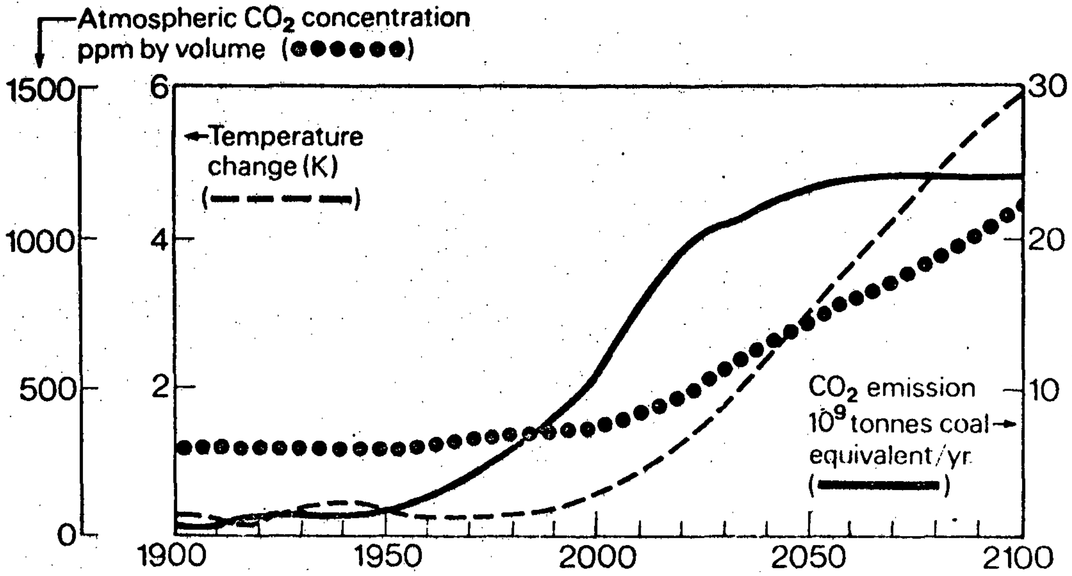
Figure 5



Greenhouse effect: CO_2 reflects heat, warms earth

Fig. 6

CBB 779-8871



Strategy for CO_2-impact of 30TW fossil fuel (from J. Williams, IIASA)

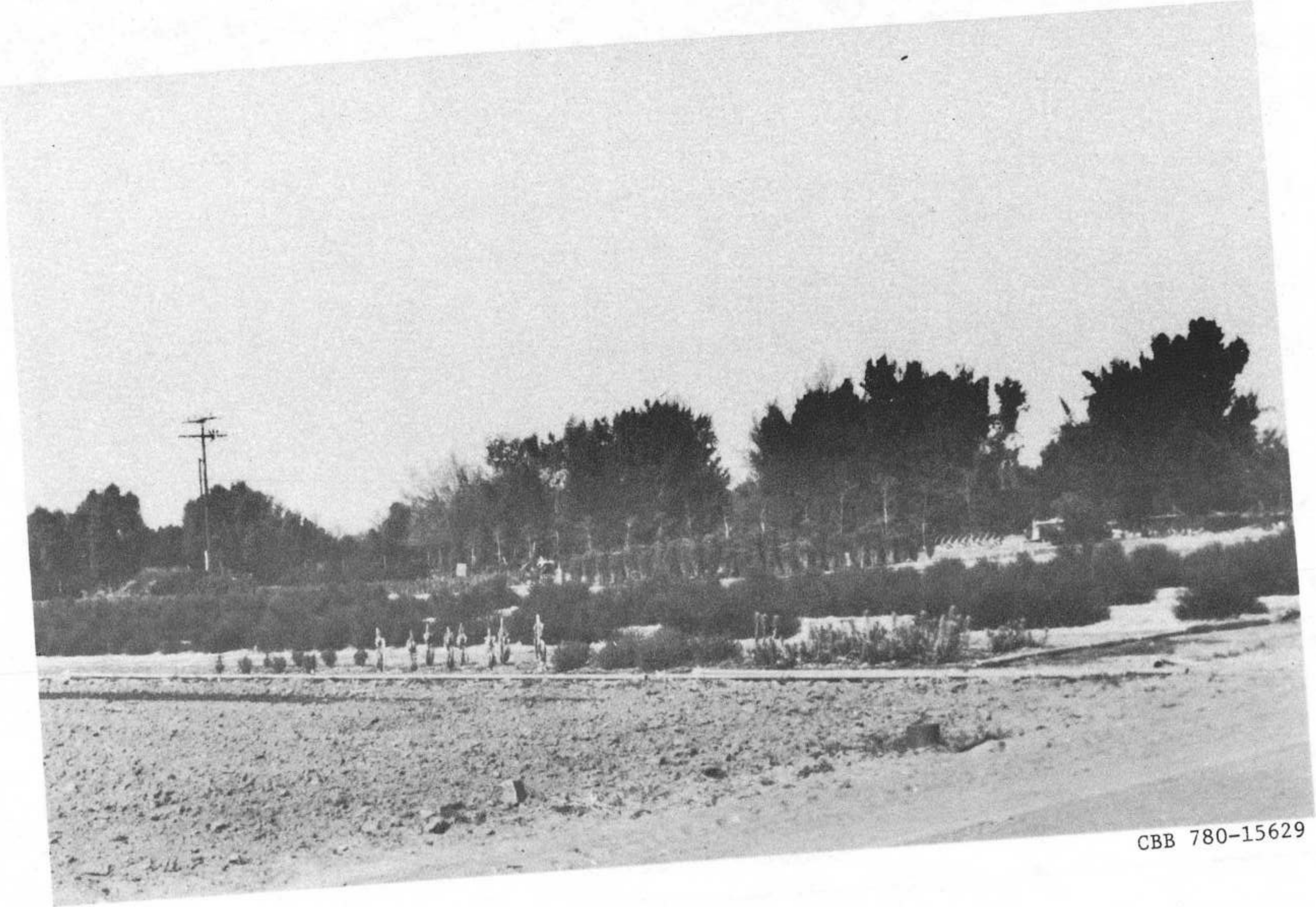
XBL 789-4223

Calvin

Figure 7

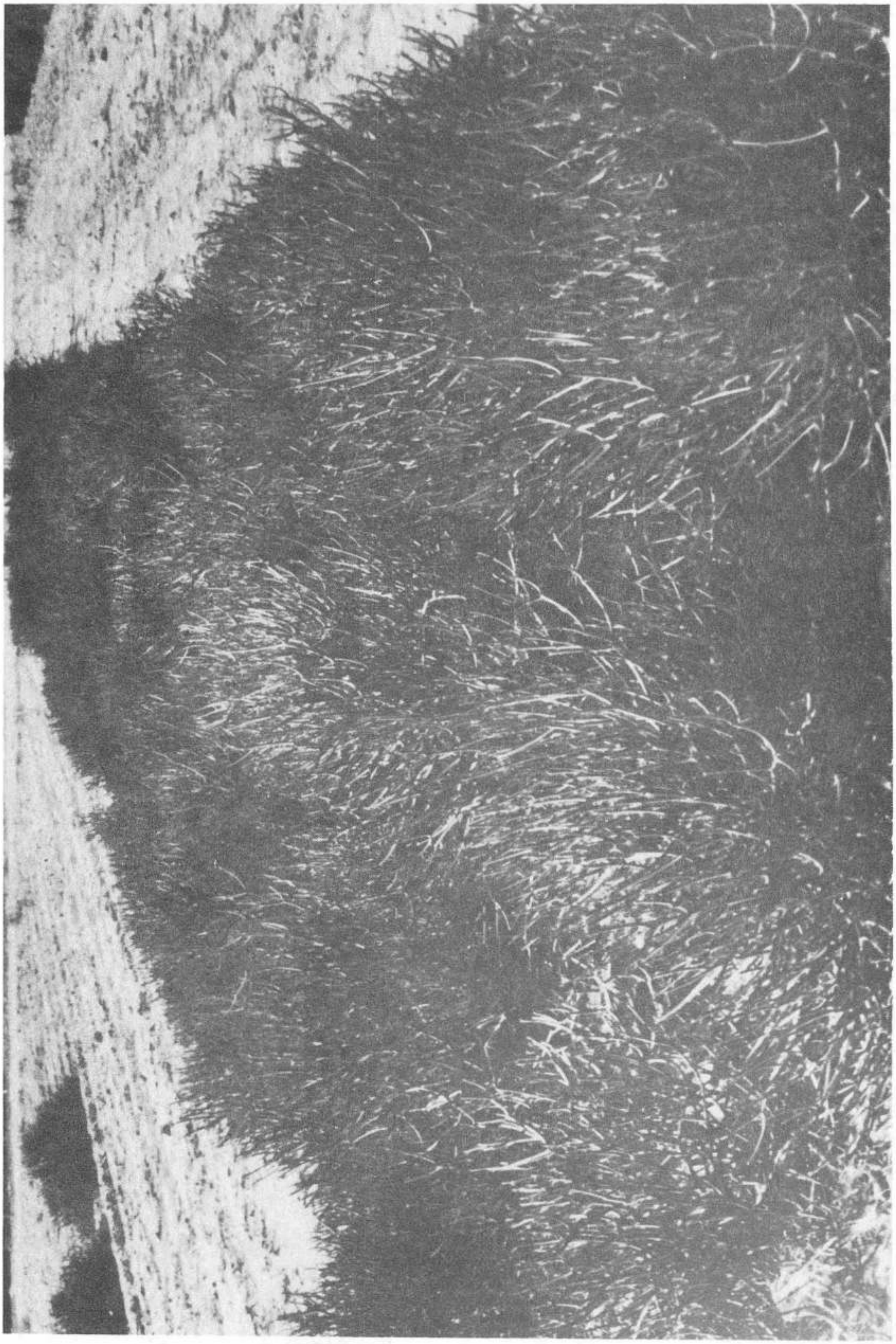
CBB 757-5366

Fig. 8



CBB 780-15629

Calvin
Figure 9

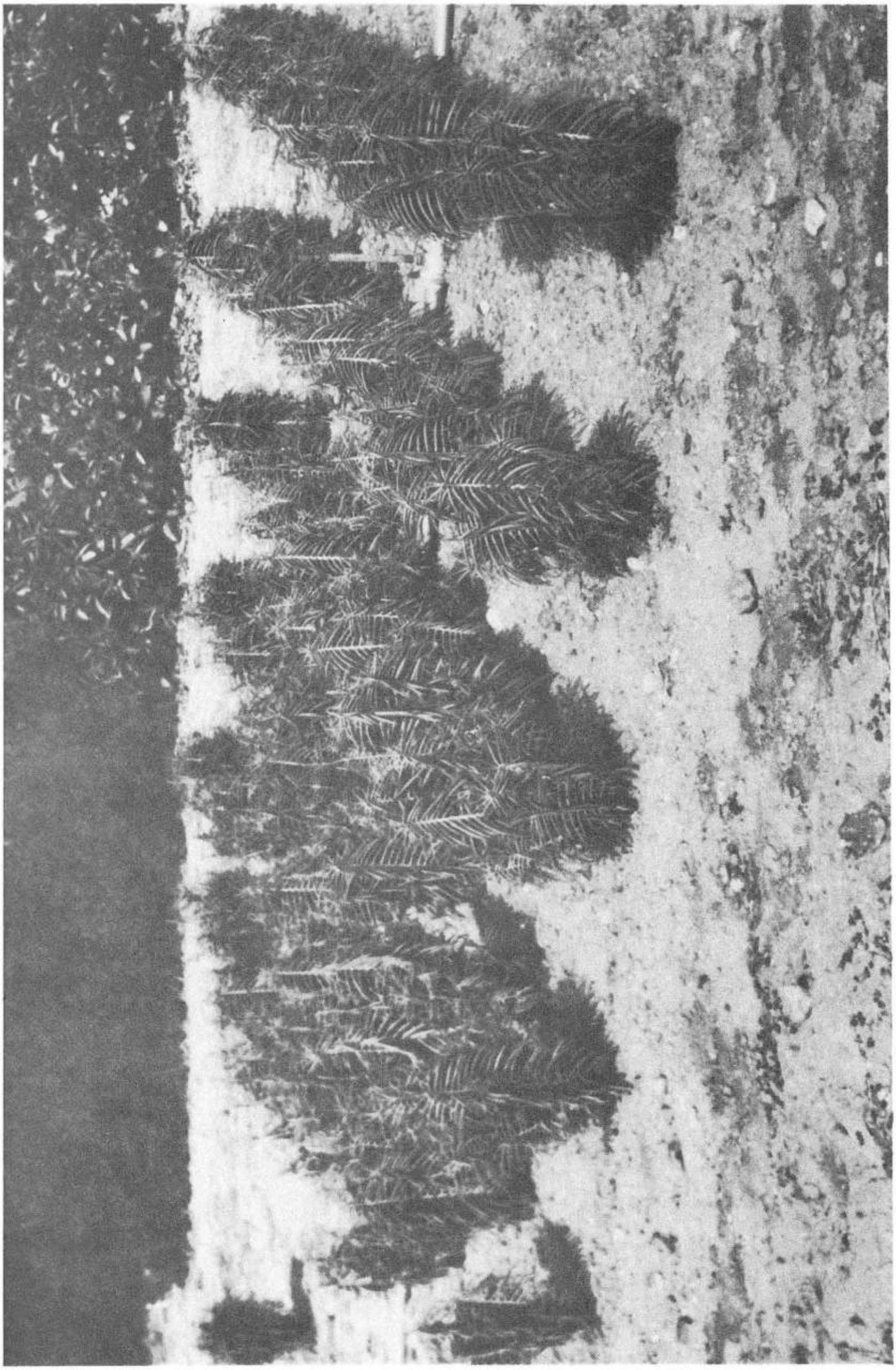


Calvin
Figure 10

CBB 780-15631

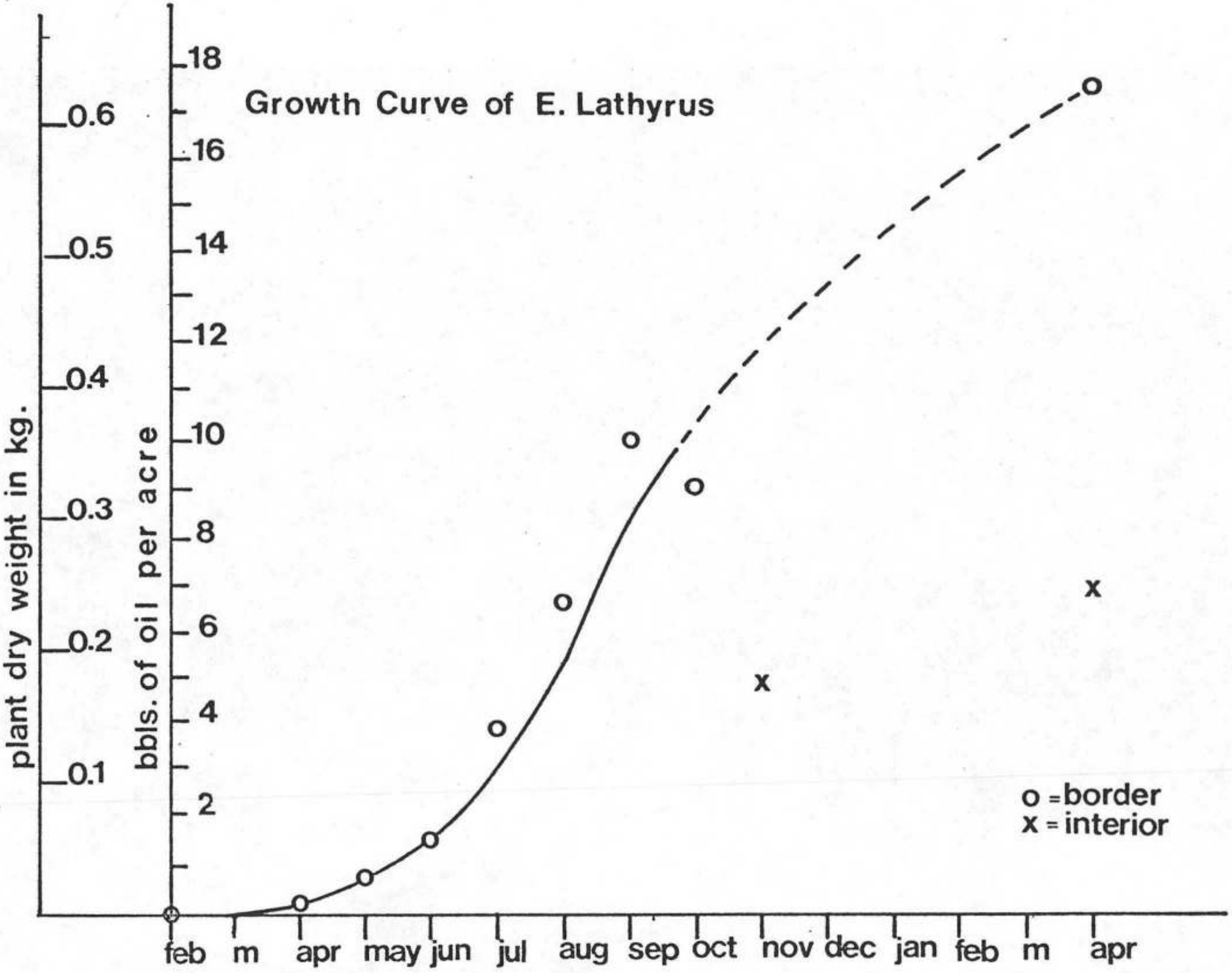
Calvin
Figure 11

CBB 792-2780



CBB 780-15635

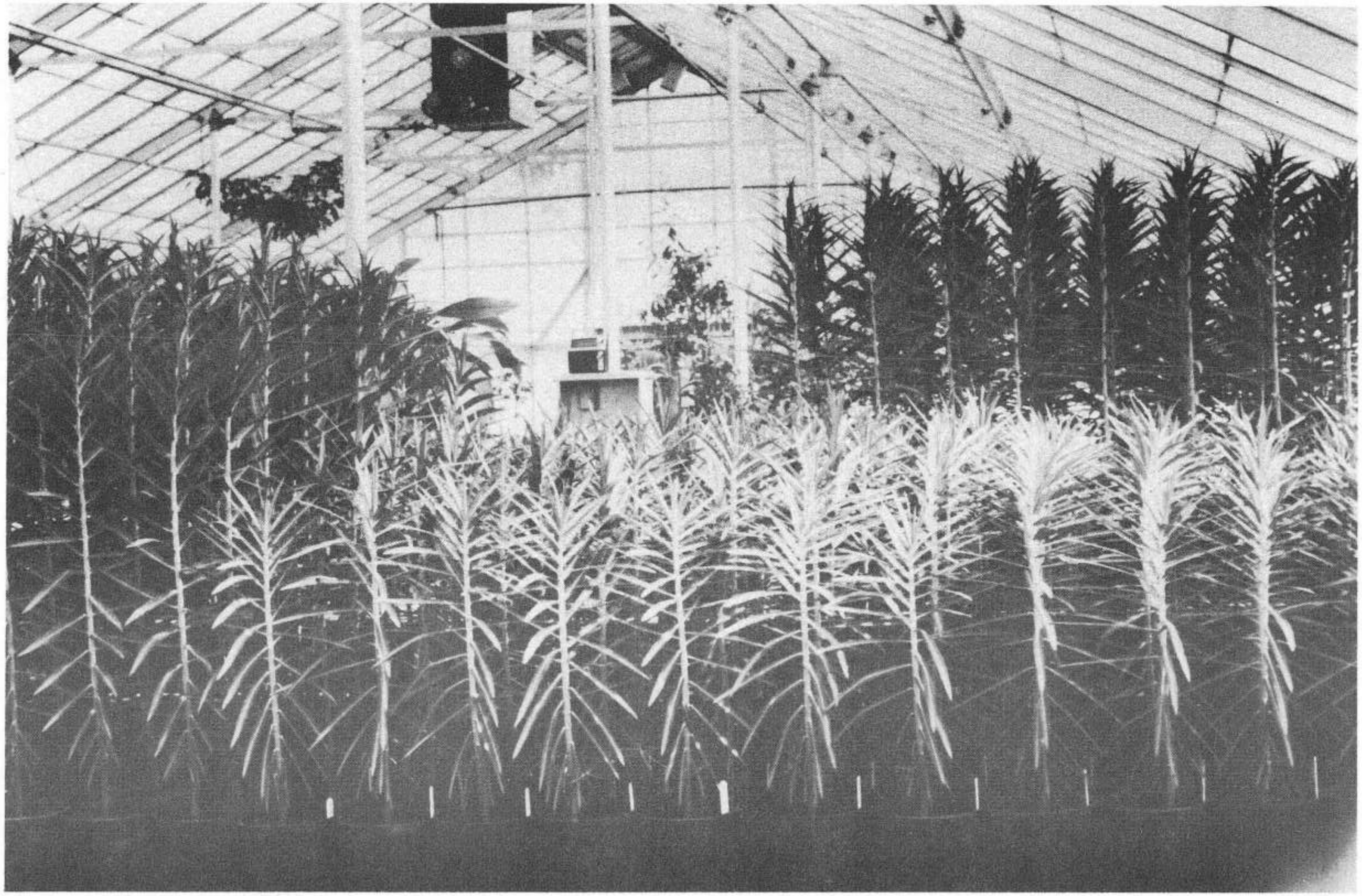
Calvin
Figure 12



XBL7810-4299

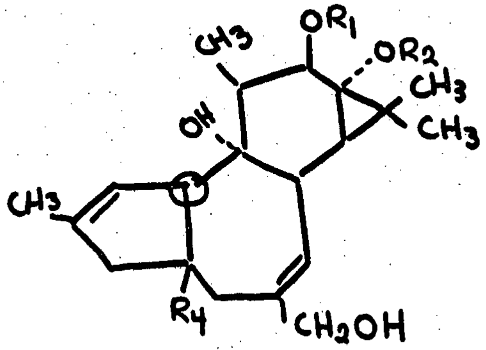
Calvin

Figure 13



Calvin
Figure 14

CBB 792-2782



FOUND IN LATEX
OF
E.TIRUCALLI.

DIESTERS OF PHORBOL.
(R_4 = OH).

R_1	R_2
2,4,6,8,10-tetradecapentaenoyl.	Ac.
Ac	2,4,6,8,10 tetradecapentaenoyl
2,4,6,8-tetradecatetraenoyl	Ac
2,4-octadieonyl	Ac
2,4,6-decatrienoyl.	Ac.

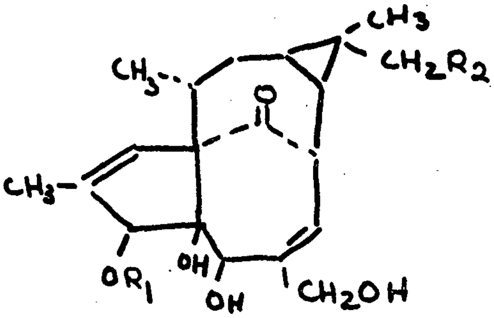
DIESTERS OF 4-DEOXYPHORBOL. R_4 = H

R_1	R_2
12-decatrienoyl	Ac
Ac	2,4,6-decatrienoyl
Ac	2,4,6,8 tetradeca-tetranoyl.

INGENOL IS PRESENT IN VERY SMALL AMTS.

Calvin
Figure 15

FOUND IN E. LATHYRIS



ESTERS OF INGENOL:

R_1 = hexadecanoate
R_2 = H
} Found in Latex active = 0.1 of TPA.

R_1 = 3-tetradeca-2,4,6,8,10-pentaenoate.
R_2 = H
} in seed oil.

Active. ~ TPA.

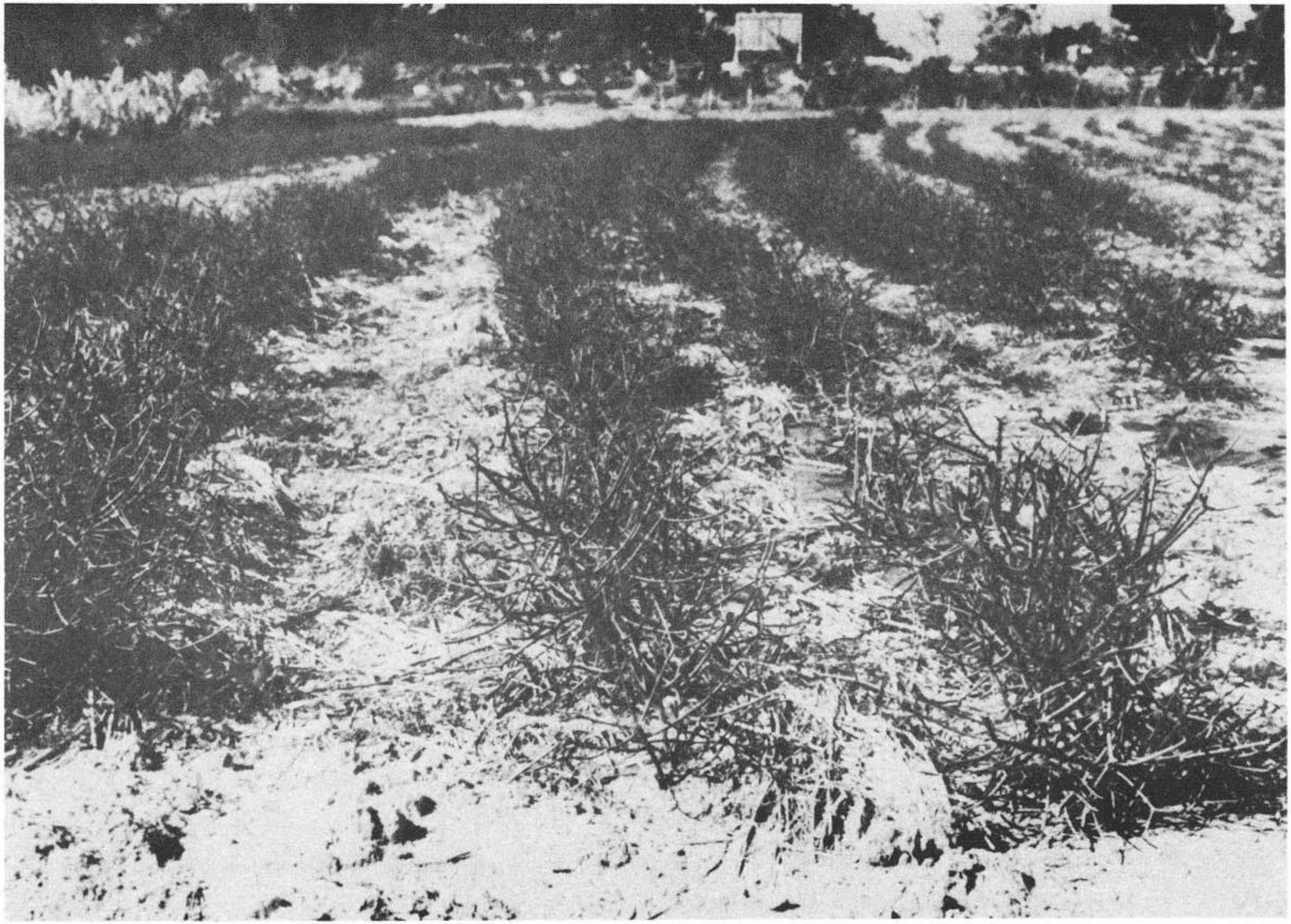
Also found but inactive:

16-hydroxy ingenol: R_2 = OH.

PHORBOL ESTERS PRESENT IN EXTREMELY SMALL AMOUNTS.

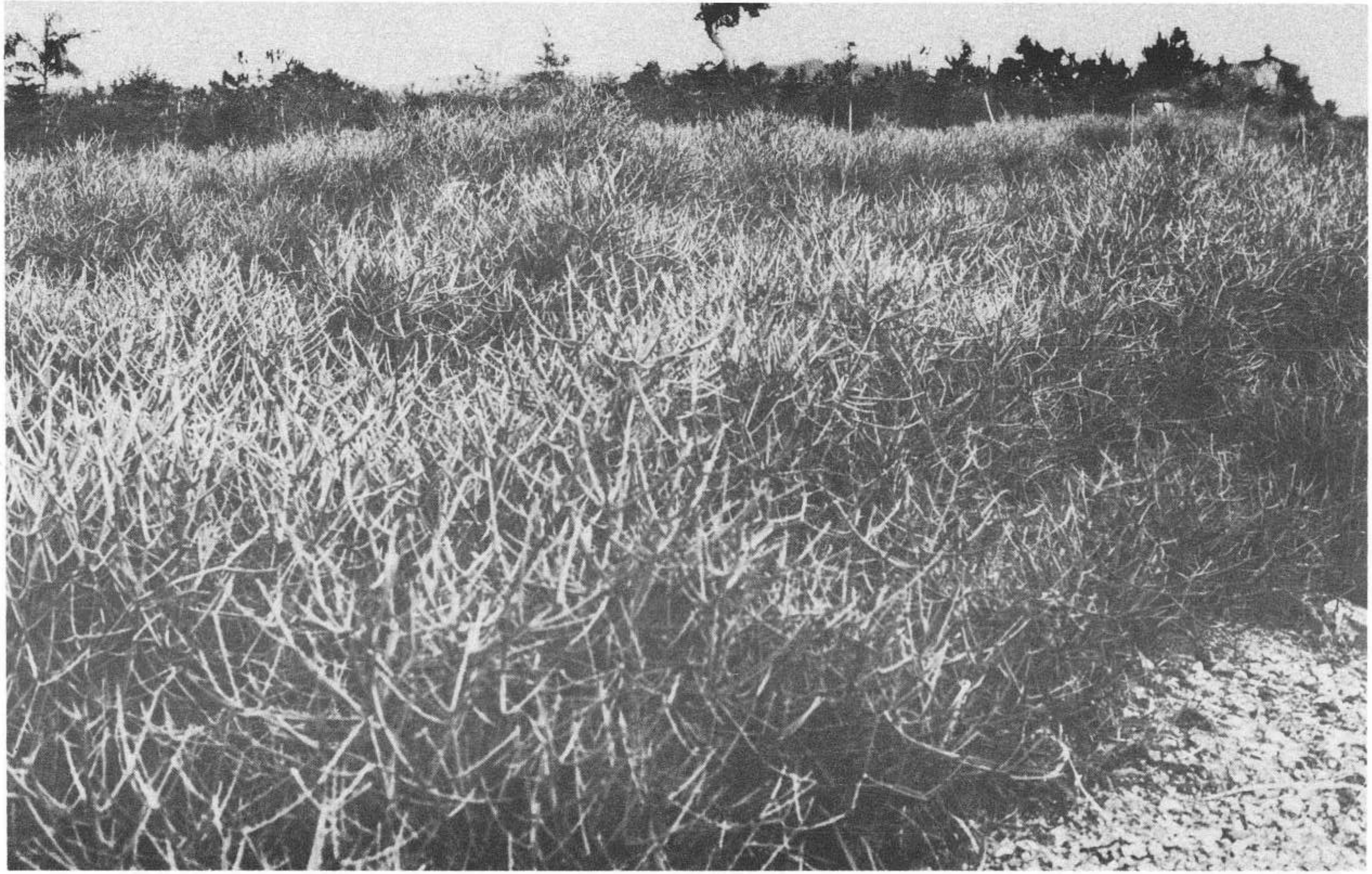
Calvin

Figure 16



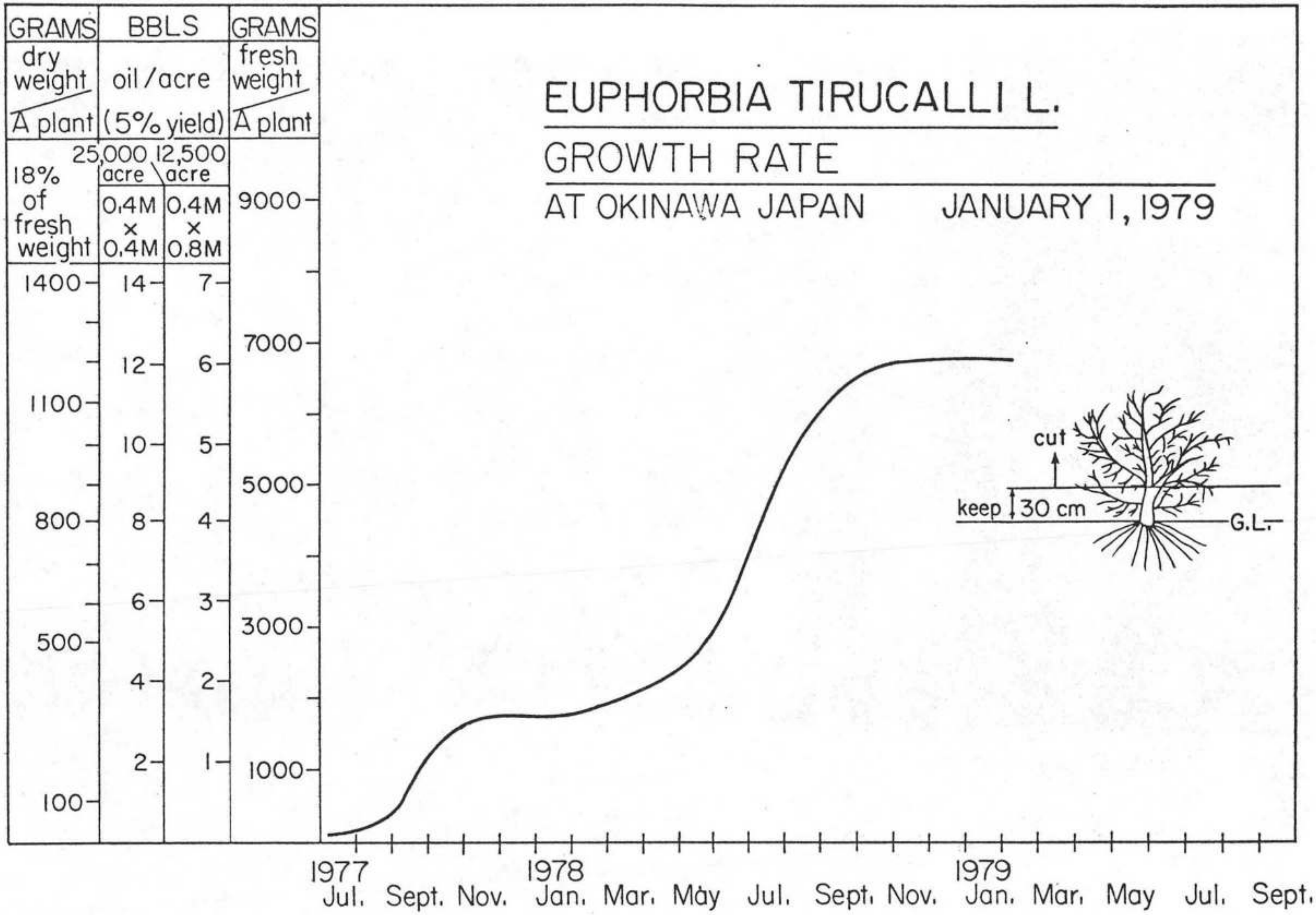
Calvin
Figure 17

CBB 785-6449



Calvin
Figure 18

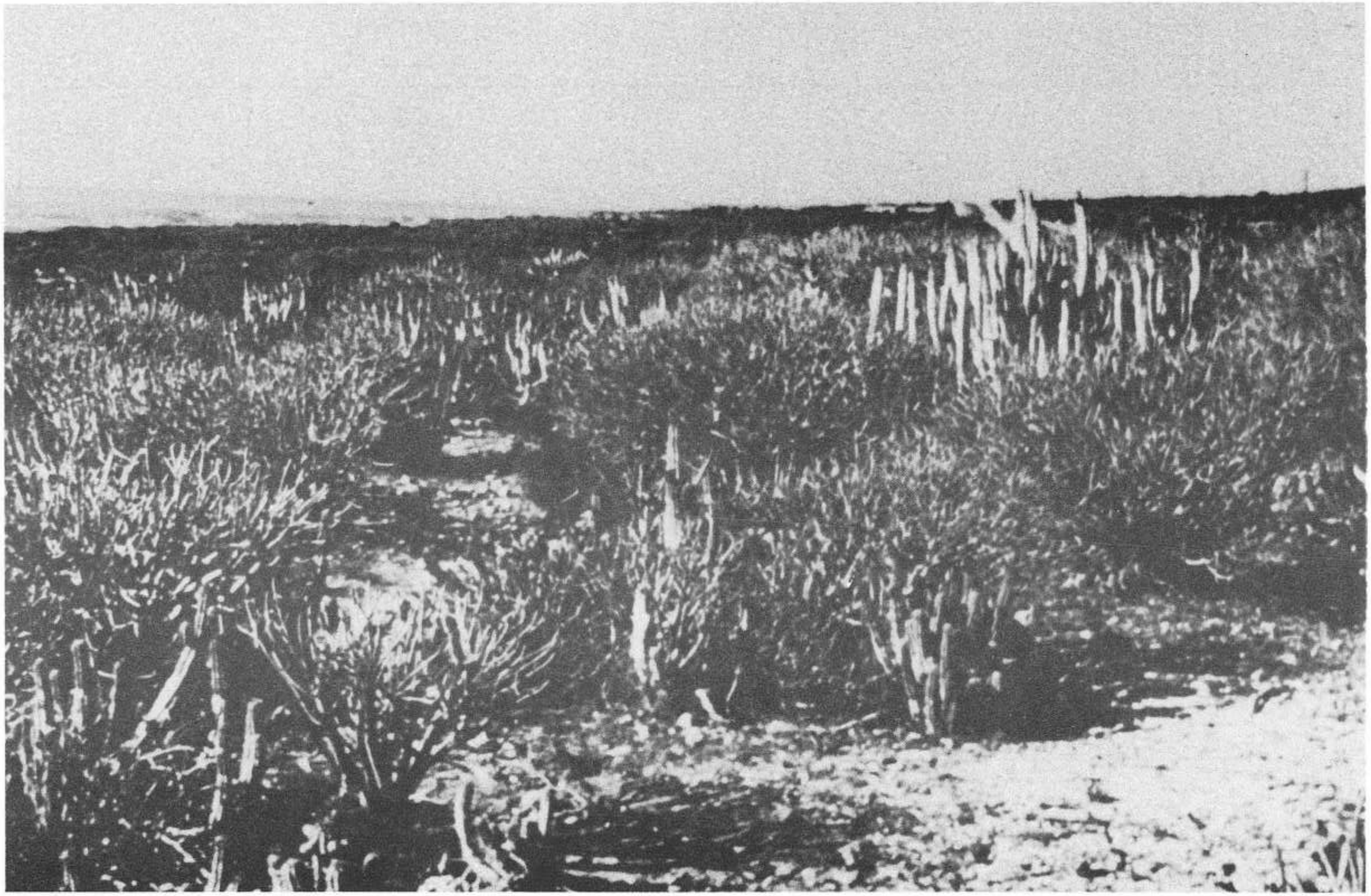
CBB 793-3190



XBL793-4687

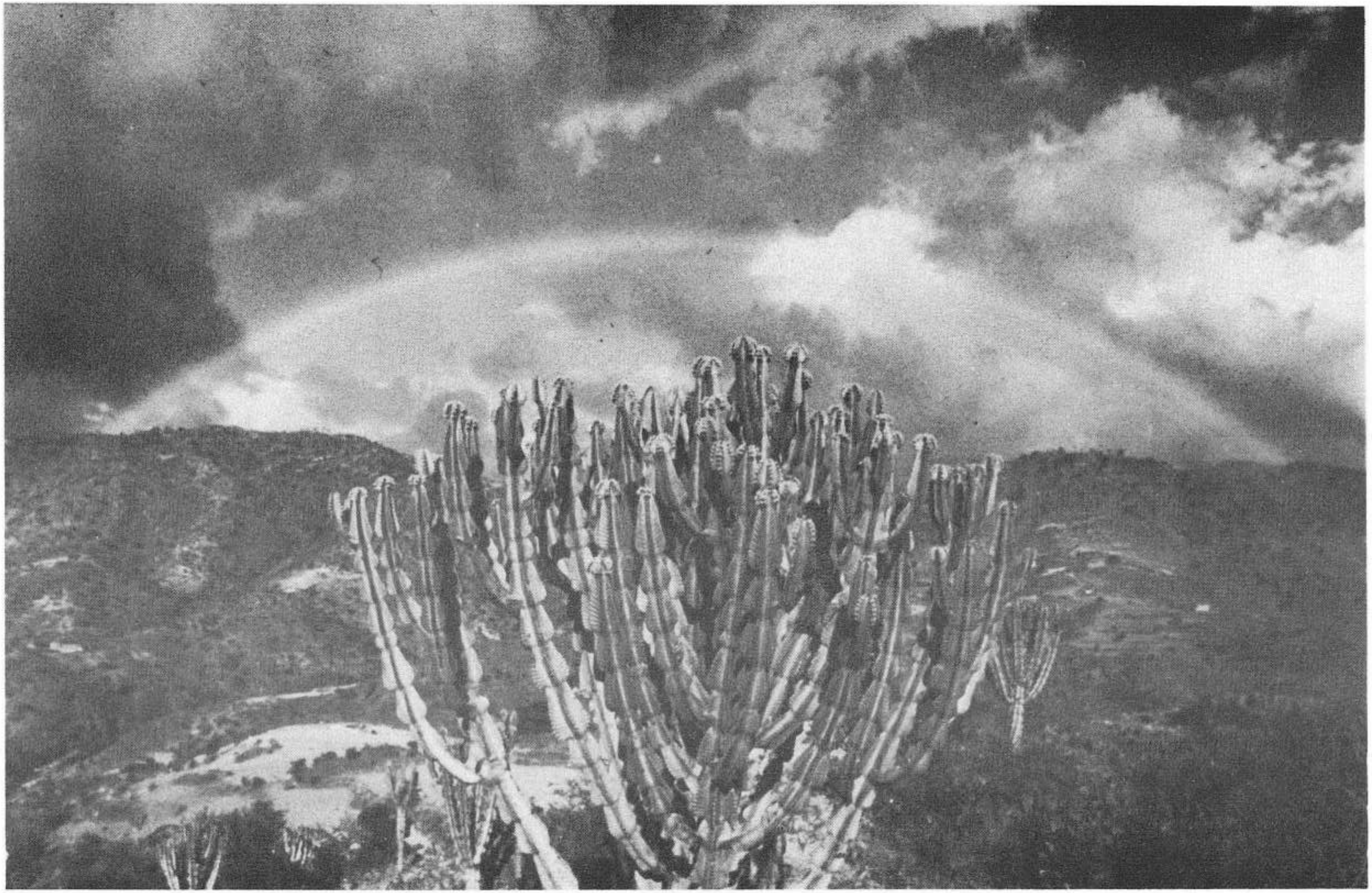
Calvin

Figure 19



Calvin
Figure 20

CBB 791-210



Calvin
Figure 21

CBB 792-2288

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